

Scheepers, C., Raffray, C. and Myachykov, A. (2017) The lexical boost effect is not diagnostic of lexically-specific syntactic representations. *Journal of Memory and Language*, 95, pp. 102-115. (doi:[10.1016/j.jml.2017.03.001](https://doi.org/10.1016/j.jml.2017.03.001))

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Deposited on: 06 March 2017

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**The lexical boost effect is not diagnostic of lexically-specific syntactic
representations**

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Abstract

Structural priming implies that speakers/listeners unknowingly re-use syntactic structure over subsequent utterances. Previous research found that structural priming is reliably enhanced when lexical content is repeated (*lexical boost effect*). A widely held assumption is that structure-licensing heads enjoy a privileged role in lexically boosting structural priming. The present comprehension-to-production priming experiments investigated whether head-constituents (verbs) versus non-head constituents (argument nouns) contribute differently to boosting ditransitive structure priming in English. Experiment 1 showed that lexical boosts from repeated agent or recipient nouns (and to a lesser extent, repeated theme nouns) were comparable to those from repeated verbs. Experiments 2 and 3 found that increasing *numbers* of content words shared between primes and targets led to increasing magnitudes of structural priming (again, with no ‘special’ contribution of verb-repetition). We conclude that lexical boost effects are not diagnostic of lexically-specific syntactic representations, even though such representations are supported by other types of evidence.

Keywords: syntactic priming; lexical boost; sentence production

Highlights

- We used a comprehension-to-production paradigm to investigate whether the verb plays a special role in boosting PO/DO priming.
- We registered argument-related lexical boost effects that were of the same magnitude as the verb-related lexical boost effect.
- We also found evidence for ‘cumulative’ lexical boost effects: the more content words (of any type) are shared between prime and target, the higher the magnitude of syntactic priming.
- We conclude that short-term lexical boost effects are not diagnostic of lexicalized syntax but may instead be indicative of a separate explicit memory mechanism (cf. Chang, Dell, & Bock, 2006).

The Lexical Boost to Structural Priming

A well-documented psycholinguistic finding is that speakers tend to repeat aspects of syntactic structure from one utterance to the next (e.g., Bock, 1986; Bock & Loebell, 1990; Bock, Loebell, & Morey, 1992; Branigan, Pickering, & Cleland, 2000; Cleland & Pickering, 2003; Corley & Scheepers, 2002; Pickering & Branigan, 1998; for reviews and meta-analyses, see Pickering & Ferreira, 2008; Mahowald, James, Futrell, & Gibson, 2016). This finding has been reported for a wide range of syntactic alternations, including active/passive sentences (e.g., *one of the fans punched the referee* vs. *the referee was punched by one of the fans*), prepositional object (PO) versus double object (DO) ditransitive structures (e.g., *a rock climber sold some cocaine to an undercover agent* vs. *a rock climber sold an undercover agent some cocaine*), and noun modification using a pre-nominal adjective or a post-nominal relative clause (e.g., *the red sheep* vs. *the sheep that's red*), to name but a few. Critically, in each of these cases, at least two different syntactic structures are available to express the same message, and the speaker must choose between them. This choice is affected by the form of a previously encountered utterance: After using one type of structure in a ‘prime’ trial, people are more prone to use the same structure in a subsequent ‘target’ trial when faced with the same structural choice. This phenomenon is generally referred to as *syntactic priming* (or *structural priming*, respectively). It indicates that speakers or listeners must retain some form of abstract structural representation in memory once they produced or understood an utterance, which they can re-use during subsequent sentence formulation or comprehension.

Interestingly, while syntactic priming does not require the repetition of lexical content across utterances, it has been shown to be considerably enhanced by the latter. To give a classical example, Pickering and Branigan (1998; see also Corley &

Scheepers, 2002) investigated ditransitive structure priming using a written sentence-completion task. They found that the tendency to re-use the (PO or DO) structure of a prime in a subsequent target trial was reliably stronger when the main verb was repeated between prime and target. Cleland and Pickering (2003) reported a similar effect for nouns. They had participants produce noun phrase descriptions such as *the red sheep* or *the sheep that's red*, and found that the tendency to repeat syntactic structure (pre-nominal adjective vs. post-nominal relative clause) was enhanced if the head noun (*sheep*) was repeated between prime and target.

This so-called ‘lexical boost’ effect (enhanced structural priming in the context of shared lexical content between prime and target) has frequently been taken as evidence for lexicalized representations of structural knowledge, i.e. the idea that abstract syntactic representations are associated with the morphosyntactic properties of individual lexical items in long-term memory. For instance, Pickering and Branigan (1998) suggested an explanation of their own findings based on the inclusion of so-called combinatorial nodes into the lemma level of the production lexicon. In their account, individual lexical items (such as verbs) are associated with combinatorial nodes which encode the syntactic frames that are licensed by those items. For example, the lemma node for an alternating ditransitive verb such as *sell* is connected to a combinatorial node encoding a PO structure (e.g., [_{VP} [_V *sell*] [_{NP} *an umbrella*] [_{PP} *to a tourist*]]) as well as to another combinatorial node encoding a DO structure (e.g., [_{VP} [_V *sell*] [_{NP} *a tourist*] [_{NP} *an umbrella*]]). Each structural configuration is represented by a distinct combinatorial node linked to the verb, and each combinatorial node is shared with other verbs that can project the same structure. Use of *sell* with a PO construction (e.g., *a rock climber sold some cocaine to an undercover agent*) would activate the lemma node for *sell* and also the PO

combinatorial node, and their co-activation would lead to a strengthening of the connection between them. Assuming that activation patterns do not decay immediately, activation of the PO node would make it easier for the same PO node to reach activation threshold in a subsequent trial. Thus, when the speaker faces a ditransitive structure choice again, but involving another ditransitive verb such as *give*, he/she will be more likely to use the previously produced PO rather than the alternative DO structure. Since the combinatorial nodes are shared between different lemmas (e.g. *sell*, *give*, *send*, *show*, etc.), structural priming occurs even if subsequent trials do not employ the exact same verb. Importantly, however, if the critical verb lemma is repeated between one utterance and the next, then not only residual activation of the combinatorial node, but also residual activation of the *link between combinatorial node and lemma node* will create a bias towards re-using the relevant structure. This effectively explains the lexical boost effect, whereby structural priming is enhanced whenever subsequent utterances employ the same lemma (e.g., the verb *sell* in both prime and target trial).

In sum, Pickering and Branigan's (1998) argument is that residual activation of abstract structure (encoded in combinatorial nodes) and its connection with individual word lemmas are at the heart of syntactic priming, and more specifically, lexical boosts to such effects, which since then have been demonstrated cross-linguistically across a range of different constructions, paradigms, and processing modalities (e.g., Arai, van Gompel, & Scheepers, 2007; Branigan, Pickering, & Cleland, 2000; Cleland & Pickering, 2003; Gries, 2005; Hartsuiker & Kolk, 1998; Hartsuiker & Westenberg, 2000; Hartsuiker, Bernolet, Schoonbaert, Speybroeck, & Vanderelst, 2008; Pickering & Branigan, 1998; Traxler, 2015; Traxler, Tooley, & Pickering, 2014; Segaert, Kempen, Petersson, & Hagoort, 2013; see also Mahowald et al., 2016).

An important theoretical implication of Pickering and Branigan's (1998) model appears to be that sharing of uncritical *non-head* constituents between prime and target should not (or not as much) result in boosted syntactic priming. This is because it must be the licensing head of a phrase that is linked to the kind of combinatorial information envisaged in Pickering & Branigan's (1998) model. Indeed, PO and DO structures are grammatically licensed by ditransitive verbs, and not by argument nouns or other types of constituents. A special role of the verb is also suggested by recent findings showing that repetition of verb *senses* contributes to the lexical boost in ditransitive structure priming (Bernolet, Coleman, & Hartsuiker, 2014).

In contrast, Chang, Dell, and Bock (2006) proposed a very different account of the previous findings. According to their model, structural priming is not a reflection of short-term activation (and gradual decay) of syntactic representations that are shared between different word lemmas, but rather the result of *implicit learning*, i.e. gradual changes in the weights of (implicitly acquired) long-term associations representing abstract syntactic knowledge. Curiously, simulations based on a formal implementation of their model failed to replicate any lexical boost effects¹, while otherwise being able to account for a variety of other findings related to syntactic priming. Chang et al. (2006) therefore conjectured that the lexical boost of syntactic priming may actually be distinct from structural priming per se: “*We hypothesize that lexical enhancement of priming is not due to the weight-change mechanisms that lead*

¹ Importantly, this does not mean that implicit learning accounts are incapable of modelling verb-related structural preferences. For example, Chang, Janciauskas, & Fitz (2012) and Twomey, Chang, & Ambridge (2014; 2016) have shown that such a model *can* acquire long-term associations between individual lexical items (e.g. verbs) and syntactic structures. However, this implicit learning process happens gradually and over relatively long periods of time, whereas the lexical boost effects we refer to in this paper are typically strong enough to be observable in the short term (see in particular Chang et al., 2012, p. 265). Also note that the issue of verb-related structural preferences is indeed *orthogonal* to whether or not the verb is shared between prime and target (cf. lexical boost).

to long-lasting structural priming. Rather, they are due to explicit memory for the wording of the prime. When the target is being planned, the repeated content word serves as a cue to the memory of the prime and this biases the speaker to repeat its structure. This explicit memory component to priming is distinct from the model's weight-change mechanism." (p. 275). Interestingly, assuming that potentially *any* content word can act as retrieval cue to the wording of the prime, this hypothesis does not necessarily imply a special role of the verb in lexically boosting PO/DO priming.

These contrasting theoretical views motivate the following general question: While lexical boost effects are well established and robust, do phrasal heads (e.g., verbs in ditransitive verb phrases) play a more important role in boosting structural priming than non-head constituents? McLean, Pickering, and Branigan (2004) reported a series of PO/DO priming experiments that partially addressed this issue. Across experiments, they manipulated (a) the number of argument nouns repeated between primes and targets (all three [agent, recipient, and theme] vs. none) and (b) specific argument nouns (theme or recipient) repeated between primes and targets. Verbs were never repeated in their experiments. As for (a), McLean and colleagues found a massive structural priming effect (ca. 75%) when all three nouns were repeated as compared to when no lexical repetition occurred (ca. 37%). Interestingly, related to (b) they found a reliable lexical boost effect when only the theme or only the recipient noun was shared between prime and target. Although the report does not contain any statistical comparisons between experiments, the priming effect appeared stronger when the recipient noun was repeated than when the theme was repeated. With regards to our general question outlined above, these are highly relevant findings because they suggest that lexical boost effects are at least not *bound* to the licensing head of the ditransitive verb phrase: clear lexical boost effects on PO/DO

priming can also be observed when only argument nouns (but not verbs) are shared between primes and targets. Still, one important aspect of our question remains unanswered, namely whether priming with repeated verbs is different from priming with repeated nouns. In other words, while lexical boost effects on syntactic priming are not restricted to repeating licensing heads, it is still possible that repeating the verb between prime and target will lexically boost PO/DO priming even more than repeating any of the argument nouns, given that the verb enjoys a special role in licensing PO/DO structures.

The experiments reported in this paper will also focus on ditransitive structure priming as a means to examine the effects of shared lexical content between primes and targets. Our main question refers to the ability of non-head constituents to boost syntactic priming of PO/DO structures, and whether such lexical boost effects differ from those associated with sharing the verb between primes and targets. We report three experiments that investigated which types of constituents contribute most to lexical boost effects on PO/DO priming, and whether an increase in the number of content words shared between primes and targets will lead to a corresponding increase in the magnitude of syntactic priming.

All three experiments employed a comprehension-to-production priming task similar to that reported in Ferreira (1996). On each critical pairing of trials, participants first read out a PO or DO prime sentence (e.g., *the cardinal gave the envelope to the jury* or *the cardinal gave the jury the envelope*). In the immediately following target trial, they saw a randomly arranged array of content words (comprising two animate nouns, one inanimate noun, and an alternating ditransitive verb) from which they had to construct a sentence. The intended subject (or agent) noun in this target array of words was always highlighted by a distinct color, and

participants were instructed to start their sentences using the highlighted word. Since the target arrays contained no function words or other types of syntactic cues, participants were free to produce either PO or DO sentences in the target trials. Experiment 1 compared a baseline condition (with no lexical overlap between prime and target) to conditions in which either the agent noun, the verb, the recipient noun, or the theme noun were repeated between prime and target. Experiments 2 and 3 manipulated lexical overlap in terms of *how many* content words were repeated between primes and targets. Here, the main question was whether – irrespective of type of constituent (head vs. non-heads) – an increase in the number of content words shared between primes and targets would lead to a proportional increase in structural priming.

Experiment 1

This experiment employed a two-factorial within-subjects / within-items design. For each item, two independent variables were manipulated. The first was the structure of the prime sentence (henceforth Prime Structure), which came in two levels: The prime was either a prepositional object (PO) dative sentence (e.g. *the cardinal gave the envelope to the jury*) or a double-object (DO) dative sentence (e.g., *the cardinal gave the jury the envelope*). The second factor, Lexical Overlap, concerned whether a content word from the prime sentence was repeated in the subsequent target array of words. This second factor had five levels: No Overlap (the target array did not contain any words from the prime sentence), Agent Overlap (the agent noun from the prime sentence was repeated in the target array), Verb Overlap (prime sentence and target array contained the same verb), Recipient Overlap (the recipient noun from the prime sentence was repeated in the target array) and Theme Overlap (the theme noun from the prime was repeated in the target).

Method

Participants

Sixty undergraduate students from the Glasgow and Edinburgh student communities were paid to participate. They were all native English speakers and had no reported reading difficulties. All participants gave informed consent before taking part.

Materials and design

Sixty material sets were created (see Appendix A), each comprising two types of prime sentences (1) that were crossed with five types of target word-arrays (2), yielding ten different prime-target-pairings (experimental conditions) per item:

(1) a. *The cardinal gave the envelope to the jury.*

b. *The cardinal gave the jury the envelope.*

(2) a. {editor, sent, critic, manuscript}

b. {cardinal, sent, critic, manuscript}

c. {editor, gave, critic, manuscript}

d. {editor, sent, jury, manuscript}

e. {editor, sent, critic, envelope}

The PO prime sentences (1a) always started with a definite subject/agent noun phrase followed by a ditransitive verb in past tense, a definite noun phrase referring to the theme, and a prepositional phrase referring to the recipient (or beneficiary) of the ditransitive event. To be able to use a wide range of verbs, types of prepositional phrases in the PO primes varied across items: Half of the items employed ‘recipient’ datives as in (1), whereas the other half were ‘beneficiary’ datives using the preposition “for” (e.g., *the confectioner baked the tart for the bishop*). Since results were comparable between the two groups of items (see also Bock, 1989, who showed

that type of preposition does not matter for PO priming), we will not distinguish between them in the remainder of this paper. DO prime sentences (1b) were double-object versions of the primes in (1a), such that the verb was followed by two noun phrases: the first referring to the recipient (or beneficiary) and the second to the theme of the described event.

The examples in (2) illustrate the target arrays of words that the prime sentences were paired with. They always contained three nouns (two animate and one inanimate) as well as a ditransitive verb in past tense. As will become clear in the *Procedures* section, the words per array were always presented in a random fashion on screen (not ‘ordered’ as in [2]), and one of the animate nouns per array (the intended subject/agent, underscored in [2]) was distinguished by a different font colour from the other words. The target arrays came in five different versions. In the first (2a), the words were all different from the content words of the preceding prime sentence (No Overlap condition). In the second (2b), the subject/agent noun was repeated from the prime sentence (Agent Overlap condition). The third version (2c) contained the same verb as the previous prime sentence (Verb Overlap condition) – NB: this version was conceptually close to the lexical overlap conditions in previous work on PO/DO priming (e.g., Pickering & Branigan, 1998; Corley & Scheepers, 2002). In the fourth version (2d), the recipient (or beneficiary) noun from the previous prime sentence was repeated (Recipient Overlap condition). Lastly, in the fifth version (2e), the inanimate noun was repeated (Theme Overlap condition).

In addition to the critical $60 \text{ (items)} \times 10 \text{ (conditions)} = 600$ prime-target pairings, there were 180 filler items. Half of the fillers were whole sentences, but different in content and structure from the critical ditransitive sentences (comprising copular structures like *the rocker was an overnight sensation*, intransitives like *the*

mermaid was waiving in the distance, or comparatives like *the knight was stronger than the pageboy*). The other half of fillers were four-word arrays which, again, encouraged the generation of structures that were different from the critical PO/DO sentences (e.g., {*cocky, chauffeur, terrible, driver*}, {*senile, veteran, suffered, greatly*}, or {*hunk, more, attractive, mate*}; note that some of the filler arrays required the inclusion of a verb for sentence generation).

The materials were allotted to ten different material lists. Each list contained 60 critical items (prime-target pairs), as well as the 180 fillers, yielding 300 individual trials per list. There were six items in each experimental condition per list, and across the ten lists, item-condition combinations were fully counterbalanced using a Latin square. Each list was seen by six participants. For presentation, the trials per list were arranged in a pseudo-random order such that (a) each list started with six fillers as practice-trials and (b) each critical prime-target pair was preceded by at least two filler trials, randomly chosen from the combined pool of sentence and word-array fillers. Because of the latter, no regular sequence of sentence versus word-array trials was detectable.

Procedure

The experiment was carried out in a lab at either Glasgow or Edinburgh University. A typical session lasted for about 45 minutes. Stimulus presentation and recording of responses was controlled using DMDX (Forster & Forster, 2003) installed on a Dell Optiplex PC with 17 inch CRT (Glasgow), respectively a 17 inch Dell Latitude notebook with LCD display (Edinburgh). Connected to the PC/notebook was a Logitech 980369-0403 microphone headset for audio recordings.

Participants were informed that the experiment involved two different tasks (see Figure 1), and that their spoken responses would be audio-recorded. On so-called

‘reading aloud’ trials (used for primes), they would see a sentence printed in *blue* letters on a black background, and their task was to read the sentence aloud. On ‘sentence generation’ trials (used for targets), they would see a randomly arranged array of four words (three printed in *red* and one printed in *green*, on a black background), and their task was to produce a grammatical sentence from those four words, always starting with the word printed in *green* (this meant that in the critical target trials, it was always clear to participants which one of the two animate nouns should be used as the subject/agent of the sentence). No information about the priming manipulation was given in the instructions (participants were debriefed at the end of the session), and the experiment always started with a practice block of six filler trials (three reading aloud and three sentence generation trials) in a random order before the experiment proper began.

*** Figure 1 about here ***

On ‘reading aloud’ trials, the sentence stimuli stayed on screen for 5500 ms, with an additional blank screen period of 750 ms before the next trial commenced. On ‘sentence generation’ trials, the word-array stimuli were presented for 5500 ms with an additional 1000 ms blank-screen delay before the next trial. This gave participants sufficient time to plan and articulate their responses. The sentence stimuli for reading aloud were presented on a single line in the centre of the screen. The words in each sentence generation trial were arranged in four quadrants around the centre of the screen (see Figure 1), so that two words appeared three lines above and two words appeared three lines below the horizontal midpoint. The positioning of the words in each of those arrays was randomly determined for each individual item, but stayed

fixed across the ten presentation lists. Hence, spatial layout of the words per array varied across items, but not across experimental conditions.

Response annotation

The sound recordings from the critical prime-target trials were transcribed and annotated for further analysis. Target responses were classified as one of PO, DO, or Other. A target response was coded as PO when the produced sentence started with a noun phrase headed by the designated subject/agent noun (green word), followed by the verb, a noun phrase headed by the inanimate noun (acting as the theme), and finally a prepositional phrase (headed by “to” or “for”, dependent on the verb) containing the second animate noun (acting as the recipient or beneficiary, respectively). A target response was coded as DO when the sentence started with the designated agent (as before), followed by the verb, a noun phrase headed by the second animate noun (acting as the recipient or beneficiary), and finally a noun phrase headed by the inanimate noun (acting as the theme). Target responses that did not meet any of the above criteria were coded as Other; these frequently included simple transitive structures like *the editor sent the manuscript*, passives constructions like *the editor was sent the manuscript by the critic*, or irreversible verb-particle constructions like *the editor sent off the manuscript to the critic*. Any prime-target pairing on which a participant read the prime incorrectly or failed to respond in the target was discarded from analysis, affecting less than 1% of the data.

Analysis

Data and analysis scripts for all experiments reported in this paper are available online (see Author Notes). Inferential analyses were based on Generalized Linear Mixed Models (GLMMs), using the *lme4* package in *R*. The dependent variable was binary in all reported analyses. Therefore, we always specified a

binomial logit model in the family argument of the `glmer()` function. Details of fixed effects design and predictor coding will be provided in the specific results sections. All analyses employed the maximal random effects structure justified by the design (Barr, Levy, Scheepers, & Tily, 2013). That is, we not only included by-subject and by-item random intercepts, but also by-subject and by-item random slopes for every main effect and interaction term in the fixed effects specification of any given model. The latter accounted for the fact that all manipulations were both within-subjects and within-items. In some instances (indicated where appropriate), random correlation terms had to be dropped from the model due to convergence issues. According to Barr et al. (2013, Appendix), exclusion of random correlations is unlikely to inflate Type I error rate as long as mean-centred predictor coding is used. Lastly, *p*-values for fixed factor main effects and interactions were determined via likelihood-ratio χ^2 model comparisons.

Results

The results of this and the following experiments will be reported in two subsections. The first (*Overall Priming Results*) provides a description of response distributions across experimental design cells and also reports GLMM analyses testing the presence of syntactic priming effects (averaged across levels of Lexical Overlap). The second subsection (*Lexical Overlap and Structural Repetition*) focuses on prime-structure repetition in the target trial as the dependent variable. Here, the main question is how Lexical Overlap influences the likelihood of repeating the structure of the prime in the target trial.

Overall Priming Results. Table 1 shows the distribution of target responses (PO, DO, and Other) by Lexical Overlap (five levels) and Prime Structure (two levels).

Overlap	Prime	Target Response		
		PO	DO	Other
None	PO	.510 (182)	.216 (77)	.275 (98)
	DO	.494 (177)	.229 (82)	.277 (99)
Agent	PO	.560 (200)	.235 (84)	.204 (73)
	DO	.507 (180)	.296 (105)	.197 (70)
Verb	PO	.546 (195)	.182 (65)	.272 (97)
	DO	.455 (163)	.304 (109)	.240 (86)
Recipient	PO	.550 (197)	.193 (69)	.257 (92)
	DO	.440 (158)	.287 (103)	.273 (98)
Theme	PO	.524 (188)	.248 (89)	.228 (82)
	DO	.466 (167)	.274 (98)	.260 (93)
Total		.505 (1807)	.246 (881)	.248 (888)

Table 1. Observed proportions of PO, DO, and Other target responses (absolute cell counts in brackets) for each Lexical Overlap \times Prime Structure combination in Experiment 1.

As is evident from the bottom row of the table, PO responses were generally preferred over DO responses, which were as likely as Other responses. More importantly, across Lexical Overlap conditions, the probability of producing a PO target response was consistently higher after reading a PO ($M = .538$) than after reading a DO prime sentence ($M = .473$), and conversely, the probability of a DO response was higher after a DO ($M = .278$) than after a PO prime sentence ($M = .215$).

To inferentially corroborate the descriptive evidence for priming, two binary logistic GLMMs were fitted, one predicting occurrences of PO target responses (out of all available answers) and one predicting occurrences of DO target responses (again, out of all available answers). The only fixed factor considered in these analyses was Prime Structure, which was entered in mean-centered form into each

model (deviation coding). These analyses confirmed a reliable overall priming effect – across Lexical Overlap conditions – for PO target responses ($\chi^2 = 13.544$, $df = 1$, $p < .001$) as well as for DO target responses ($\chi^2 = 11.929$, $df = 1$, $p < .001$).

Lexical Overlap and Structural Repetition. After registering a general PO/DO priming effect (see previous section), the data were re-presented in a different way so as to examine the influence of Lexical Overlap and Prime Structure on the *probability of repeating the structure of the prime in the subsequent target trial*. The corresponding (re-represented) descriptive results are shown in Table 2.

Overlap	Prime Structure		Mean
	PO	DO	
None	.510	.229	.369
Agent	.560	.296	.428
Verb	.546	.304	.425
Recipient	.550	.287	.419
Theme	.524	.274	.399
Mean	.538	.278	

Table 2. Probability of prime-structure repetition in the target trial for each Lexical Overlap \times Prime Structure combination in Experiment 1.

The marginal row and column means in Table 2 suggest (a) that the likelihood of structural repetition was higher after PO than after DO primes, (b) that relative to the No Overlap condition, prime structure repetition was more likely to occur when a content word of the prime was repeated in the target trial, and (c) that the numerically strongest lexical boost effect on structural priming was in the Agent Overlap condition.

For binary logistic GLMM modelling, the dependent variable was coded as 1 (structural repetition occurred) respectively 0 (structural repetition did not occur, which also included Other responses). A full factorial 5×2 fixed effects design was used. The two predictors Lexical Overlap and Prime Structure were entered in mean-centered form (deviation coding). Since Lexical Overlap had five categorical levels, four separate coding variables were required for this predictor. We treated the No Overlap condition as a baseline and the four coding variables represented contrasts between that baseline and each of the four remaining Lexical Overlap conditions. Due to the complexity of the analysis design, convergence could only be achieved after dropping random correlation parameters from the (otherwise maximal) random effects structure of the model. The GLMM fixed effects estimates are shown in Table 3.

Parameter	Estimate	SE	Z	p
OVL_A	0.346	0.127	2.715	.007
OVL_V	0.313	0.139	2.249	.025
OVL_R	0.294	0.129	2.284	.022
OVL_T	0.182	0.136	1.337	.181
Prime	1.424	0.247	5.760	<.001
OVL_A \times Prime	-0.154	0.262	-0.587	.557
OVL_V \times Prime	-0.267	0.268	-0.997	.319
OVL_R \times Prime	-0.162	0.260	-0.625	.532
OVL_T \times Prime	-0.200	0.287	-0.700	.484

Table 3. Fixed effect parameter estimates (in log odds units), Experiment 1. Occurrences of prime-structure repetition in the target trial were modelled by factor combinations of Lexical Overlap and Prime Structure. Parameters related to Lexical Overlap represent contrasts with the No Overlap (baseline) condition. OVL_A = Agent Overlap; OVL_V = Verb Overlap; OVL_R = Recipient Overlap; OVL_T = Theme Overlap; Prime = Prime Structure (more positive means more structural repetition after PO primes).

As already suggested by the descriptive data (Table 2), the GLMM confirmed a significant main effect of Prime Structure ($\chi^2 = 29.153$, $df = 1$, $p < .001$) due to a higher likelihood of structural repetition after PO than after DO prime sentences. The overall main effect of Lexical Overlap was marginal ($\chi^2 = 9.220$, $df = 4$, $p = .056$), and the corresponding estimates in Table 3 indicate that compared to the No Overlap condition (baseline), not only Verb Overlap but indeed also Agent Overlap and Recipient Overlap were able to reliably boost repetition of the prime structure in the target trial (Theme Overlap had a similarly positive, but unreliable effect on structural repetition). Lastly, the overall Prime Structure \times Lexical Overlap interaction was far from significant ($\chi^2 = 1.056$, $df = 4$, $p = .901$). However, it is interesting to note that the corresponding interaction parameters in Table 3 are all negative, in line with the

observation that lexical boost effects were descriptively smaller (relative to the No Overlap baseline) in the PO than in the DO prime conditions (cf. Table 2).

Discussion

Using a comprehension-to-production priming task (cf. Ferreira, 1996), Experiment 1 showed clear evidence for syntactic priming of PO/DO ditransitive structures in English, conceptually replicating previous findings in this area (see introduction). Across Lexical Overlap conditions, participants were about 6.5% more likely to produce (from a target array of content words) a PO sentence after reading out a PO rather than a DO sentence in the preceding prime trial; conversely, they were about 6.3% more likely to produce a DO structure in the target trial after encountering a DO rather than PO structure in the prime trial. And although this experiment – as well as the experiments that follow – was probably not powerful enough to detect lexically-independent PO/DO priming, a descriptive suggestion of this was already visible for the No Overlap condition on its own (see Table 1). We address the issue of lexically-independent structural priming more fully in Appendix B, where we report supplemental analyses on this matter.

Also in line with previous studies using British English participant samples was the finding of a general PO preference in responding (see also Gries, 2005). In the present experiment, participants were about twice as likely to produce PO rather than DO target structures overall (bottom row of Table 1). This is an important point to consider when interpreting the *structural repetition* results in Table 2, as it might otherwise appear that DO primes were somehow “less effective” than PO primes in influencing subsequent target responses – in fact, the reduced likelihoods of structural repetition in the DO prime conditions were merely due to a general PO bias in responding.

With regard to our main question, we also found evidence for lexical boost effects on ditransitive structure priming. Crucially, the results from Experiment 1 challenge the view that the lexical head of the ditransitive verb phrase (i.e. the ditransitive verb itself) is privileged in boosting PO/DO priming: while the likelihood of structural repetition was clearly enhanced when the verb stayed the same between prime and target (in line with previous findings), a lexical boost of roughly the same magnitude was also observed when the agent noun or the recipient/beneficiary noun was repeated; even Theme Overlap led to descriptively (if unreliably) enhanced structural priming compared to the No Overlap condition. These results suggest that (more or less) *any* lexical content repeated between prime and target can enhance structural priming to a comparable degree, a finding that seems to support Chang et al.'s (2006) conjecture whereby repeated content words in the target act as memory cues to the wording and structure of the prime.

The following two experiments were designed to test this conjecture further. Indeed, if lexical boost effects on syntactic priming rely on memory cueing, then it seems plausible to assume that an increase in the number of content words shared between prime and target (i.e., an increase in the number of memory cues available in the target trial) should lead to a corresponding increase in the strength of structural priming. A descriptive suggestion of this was already visible in the studies reported by McLean et al. (2004), cited in the introduction, where it appeared that sharing all three argument nouns (agent, recipient, and theme) between PO/DO primes and targets led to a much stronger boost in syntactic priming than sharing either only the recipient noun or only the theme noun. However, no cross-experimental comparisons were reported in McLean et al. (2004), and so we decided to address the question more systematically.

Experiment 2

Experiment 2 tested whether an increase in the amount of lexical overlap between prime and target causes increasingly more structural priming. In contrast to Experiment 1, where only one content word from the prime could be repeated in the target trial, Experiment 2 employed three new Lexical Overlap conditions (in addition to the No Overlap baseline and the Agent Overlap condition, which stayed the same as before): (1) Agent+Verb Overlap, (2) Agent+Verb+Recipient Overlap, and (3) Agent+Verb+Recipient+Theme Overlap. Thus, in Experiment 2, the number of content words shared between primes and targets increased in line with a particular sequencing of sentence constituents.

Method

Participants

Sixty new undergraduate students from either Glasgow or Edinburgh were paid to participate. They were all native English speakers and had no reported reading difficulties. All participants gave informed consent before taking part.

Materials and design

The materials (including filler items) were identical to those in Experiment 1, except for the following. The prime sentences – repeated here as (3) – were crossed with new types of target word-arrays such that there was either (4a) No Overlap, (4b) Agent Overlap, (4c) Agent+Verb Overlap, (4d) Agent+Verb+Recipient Overlap, or (4e) Agent+Verb+Recipient+Theme Overlap in lexical content between prime and target. Again, the words per array were always randomly positioned on screen, and the intended Agent – underscored in (4) – was always presented in a distinct font colour.

(3) a. *The cardinal gave the envelope to the jury.*

b. *The cardinal gave the jury the envelope.*

(4) a. {editor, sent, critic, manuscript}

b. {cardinal, sent, critic, manuscript}

c. {cardinal, gave, critic, manuscript}

d. {cardinal, gave, jury, manuscript}

e. {cardinal, gave, jury, envelope}

As in Experiment 1, the materials were allotted to ten different material lists using a Latin square. Pseudo-randomization of trials was based on the same criteria as before, and again, spatial layouts of words per target array varied across items, but not across presentation lists.

Procedure, response annotation, and analysis

Apparatus, procedure, response annotation, and analysis were the same as in Experiment 1. However, one important change in analysis was that we used *backward difference coding* for the predictor Lexical Overlap, whose levels now had an ordinal interpretation (indexing ‘increasing amounts’ of lexical overlap). This will be explained in more detail below.

Results

Overall Priming Results. Around 1.2% of the prime-target pairings were excluded from analysis due to erroneous reading of the prime or failing to respond in the target, respectively. Table 4 shows the distribution of target responses (PO, DO, and Other) by Lexical Overlap (five levels) and Prime Structure (two levels) for the remaining 98.8% of valid cases.

Overlap	Prime	Target Response		
		PO	DO	Other
None	PO	.497 (178)	.243 (87)	.260 (93)
	DO	.457 (163)	.246 (88)	.297 (106)
A	PO	.631 (224)	.194 (69)	.175 (62)
	DO	.504 (178)	.280 (99)	.215 (76)
AV	PO	.729 (261)	.165 (59)	.106 (38)
	DO	.462 (150)	.423 (149)	.151 (53)
AVR	PO	.771 (276)	.162 (58)	.067 (24)
	DO	.337 (119)	.569 (201)	.093 (33)
AVRT	PO	.830 (297)	.109 (39)	.061 (22)
	DO	.248 (88)	.699 (248)	.054 (19)
Total		.544 (1934)	.308 (1097)	.148 (526)

Table 4. Observed proportions of PO, DO, and Other target responses (absolute cell counts in brackets) for each Lexical Overlap \times Prime Structure combination in Experiment 2. None = No Overlap; A = Agent Overlap; AV = Agent+Verb Overlap; AVR = Agent+Verb+Recipient Overlap; AVRT = Agent+Verb+Recipient+Theme Overlap.

As before, PO responses were generally preferred over DO responses (bottom row of the table). Interestingly, proportions of Other responses notably decreased with increasing levels of Lexical Overlap between prime and target, apparently because increasing levels of Lexical Overlap caused more structural priming of PO and DO structures (see further below). As a result, DO target responses were now generally more frequent than Other responses.

Across Lexical Overlap conditions, the probability of producing a PO target response was consistently higher after reading a PO ($M = .692$) than after reading a DO prime sentence ($M = .394$), and conversely, the probability of a DO response was higher after a DO ($M = .444$) than after a PO prime sentence ($M = .175$). Binary

logistic GLMM analyses including Prime Structure as the only fixed factor (and with maximal random effects structure) confirmed the overall priming effect both for PO target responses ($\chi^2 = 75.315$, $df = 1$, $p < .001$) and for DO target responses ($\chi^2 = 77.952$, $df = 1$, $p < .001$).

Lexical Overlap and Structural Repetition. As in Experiment 1, the data were re-represented in terms of whether the structure of the prime was repeated in the target trial. Table 5 shows the corresponding probabilities across Lexical Overlap and Prime Structure conditions.

Overlap	Prime Structure		Mean
	PO	DO	
None	.497	.246	.372
A	.631	.280	.456
AV	.729	.423	.576
AVR	.771	.569	.670
AVRT	.830	.669	.764
Mean	.692	.444	

Table 5. Probability of prime-structure repetition in the target trial, for each Lexical Overlap \times Prime Structure combination in Experiment 2. None = No Overlap; A = Agent Overlap; AV = Agent+Verb Overlap; AVR = Agent+Verb+Recipient Overlap; AVRT = Agent+Verb+Recipient+Theme Overlap.

Again, PO prime structures were associated with a higher likelihood of structural repetition in the target trial (bottom row of Table 5), which is due to a general PO bias in target response generation (Table 4). However, it is striking to note from the rightmost column in Table 5 that the likelihood of repeating the structure of the prime in the subsequent target trial *monotonically increased* as a function of

Lexical Overlap: the more words were shared between prime and target, the more structural repetition occurred.

As in Experiment 1, occurrences of structural repetition (versus no structural repetition, including Other) were modelled in terms of a full-factorial binary logistic GLMM. The fixed factors Prime Structure and Lexical Overlap were entered in mean-centered form into the model (deviation coding). As for Lexical Overlap, there were (again) four separate coding variables, with No Overlap serving as a reference. However, since Lexical Overlap now had an ordinal interpretation (reflecting increasing numbers of content words shared between prime and target), the four coding variables were numerically scored so as to index the increase in structural repetition with each one-level increase in Lexical Overlap (*backward difference coding*). The corresponding model parameters in Table 6 therefore represent *incremental contrasts*, comparing each Lexical Overlap level to the next lower-ranked level. As in the previous study, random correlations had to be dropped from the (otherwise maximal) random effects structure of the model due to convergence issues.

Parameter	Estimate	SE	Z	p
OVL_A	0.471	0.130	3.625	<.001
OVL_AV	0.679	0.141	4.835	<.001
OVL_AVR	0.545	0.149	3.657	<.001
OVL_AVRT	0.738	0.184	4.004	<.001
Prime	1.425	0.261	5.464	<.001
OVL_A \times Prime	0.498	0.280	1.793	.073
OVL_AV \times Prime	-0.226	0.258	-0.876	.380
OVL_AVR \times Prime	-0.482	0.273	-1.766	.077
OVL_AVRT \times Prime	-0.204	0.294	-0.693	.488

Table 6. Fixed effect parameter estimates (in log odds units), Experiment 2. Occurrences of prime-structure repetition in the target trial were modelled by factor combinations of Lexical Overlap and Prime Structure. Parameters related to Lexical Overlap represent incremental contrasts (*backward difference coding*). OVL_A = Agent Overlap; OVL_AV = Agent+Verb Overlap; OVL_AVR = Agent+Verb+Recipient Overlap; OVL_AVRT = Agent+Verb+Recipient+Theme Overlap (No Overlap served as baseline); Prime = Prime Structure (more positive means more structural repetition after PO primes).

Since structural repetition was more likely after PO than after DO primes (due to a general PO bias in target responses), there was a significant main effect of Prime Structure ($\chi^2 = 26.019$, $df = 1$, $p < .001$). More importantly, there was also a very clear overall main effect of Lexical Overlap ($\chi^2 = 111.003$, $df = 4$, $p < .001$). The corresponding parameter estimates in Table 6 (based on backward difference coding for the Lexical Overlap predictor) show that this was due to a significant monotonic increase in the probability of structural repetition with every one-level increase in Lexical Overlap. The overall Lexical Overlap \times Prime Structure interaction was also significant ($\chi^2 = 10.522$, $df = 4$, $p = .032$). The corresponding estimates in Table 6 suggest that this was due to a marginally more positive lexical boost effect for PO rather than DO primes when comparing the Agent Overlap condition with the lower-

ranked No Overlap baseline, and a marginally more negative lexical boost effect for PO rather than DO primes when comparing the Agent+Verb+Recipient Overlap condition with the lower-ranked Agent+Verb Overlap condition.

Discussion

Compared to the previous experiment, Experiment 2 showed much stronger evidence for PO/DO priming: Across Lexical Overlap conditions, participants were about 29.8% more likely to produce a PO target sentence after reading a PO rather than DO prime sentence (compared to 6.5% in Experiment 1), and about 26.9% more likely to produce a DO target sentence after reading a DO rather than a PO prime sentence (compared to 6.3% in Experiment 1). An obvious reason for this increase in overall priming is that the present Lexical Overlap manipulations were far more effective than those in Experiment 1 (where, apart from the No Overlap condition, only *one* content word from the prime sentence was repeated in the target at any given time).

Indeed, looking at the structural repetition data in Table 5 and the incremental contrast parameters in Table 6, it becomes clear that the magnitude of structural priming monotonically increased as a function of the number of content words shared between prime and target: the more content words were shared, the stronger the PO/DO priming effect turned out to be. This may be coined a *cumulative* lexical boost effect.

As for a hypothesized special role of the verb, the rightmost column in Table 5 descriptively suggests that the one-level increase from Agent Overlap to Agent+Verb Overlap was indeed associated with a slightly stronger boost to structural repetition (12.0%) than the one-level increase from No Overlap to Agent Overlap (8.4%) or the one-level increase from Agent+Verb Overlap to Agent+Verb+Recipient Overlap

(9.4%). However, even the maximum difference (3.6%) was actually too small to reach significance. The latter is not only suggested by the GLMM estimates in Table 6 (the OVL_AV estimate differed by less than 1.96 *SEs* from the preceding OVL_A estimate), but also confirmed by a supplemental GLMM analysis (see online *R* script for details) yielding $\chi^2 = 0.969$, $df = 1$, $p = .325$ for the 3.6% difference. Thus, neither Experiment 1 (where the lexical boost to structural priming was numerically strongest in the Agent Overlap condition) nor Experiment 2 provided any clear evidence in support of a privileged role of the verb – or more generally, the licensing head of a phrase – in lexically boosting syntactic priming. As we will argue in the general discussion, this challenges the assumption that lexical boost effects are diagnostic of lexically-specific syntactic representations.

On the other hand, the observed cumulative lexical boost effect fits well with the idea that repeated content words in the target act as memory cues to the wording and structure of the prime (Chang et al., 2006). Obviously, the more memory cues there are, the more effective the cueing will be, thus resulting in increasingly enhanced structural priming the more content words are shared between prime and target. An important question remains, however, as to whether this cumulative lexical boost was really driven by the *number* of content words shared between prime and target, or whether constituent sequencing also played a role. Recall that in Experiment 2, the increase in Lexical Overlap was always in line with a specific order of constituents (agent, agent+verb, agent+verb+recipient, agent+verb+recipient+theme). The following experiment manipulated increasing levels of Lexical Overlap without adhering to a particular constituent order.

Experiment 3

The final experiment differed from Experiment 2 only in how we manipulated the number of content words shared between prime and target: instead of increasing the amount of Lexical Overlap by order of sentence constituents, we now picked one, two, or three content words from the prime sentence *at random* so as to repeat them in the subsequent target-array of words. Two of the five Lexical Overlap conditions stayed the same as in Experiment 2, namely the No Overlap baseline (now labelled *0-Word Overlap*), and the Agent+Verb+Recipient+Theme Overlap condition (now labelled *4-Word Overlap*). Given that the three new Lexical Overlap conditions were based on random selections of content words, we tested a larger sample of participants to ensure that word selections per Lexical Overlap condition were reasonably balanced.

Method

Participants

Eighty new undergraduate students from either Glasgow or Edinburgh were paid to participate. They were all native English speakers and had no reported reading difficulties. All participants gave informed consent before taking part.

Materials and design

The materials (including filler items) were identical to those in Experiment 2, except for the following changes to the Lexical Overlap manipulation: The Agent Overlap (4b), Agent+Verb Overlap (4c), and Agent+Verb+Recipient Overlap (4d) conditions were replaced with a 1-Word Overlap, a 2-Word Overlap, and a 3-Word Overlap condition, respectively (and the No Overlap [4a] and Agent+Verb+Recipient+Theme Overlap [4e] conditions were relabeled as *0-Word Overlap* and *4-Word Overlap*, respectively). To create the three new conditions,

content words from the prime sentences (3) were selected *at random*, on an item-by-item basis, such that either one (1-Word Overlap), two (2-Word Overlap), or three (3-Word Overlap) content words (arbitrarily chosen from the four available in each prime sentence) reappeared in the subsequent target-array for sentence production.

To ensure evenly distributed word choices for each of the three new Lexical Overlap conditions, we quadrupled the number of presentation lists: There were 10 Latin square rotations of items over experimental conditions, and for each of these 10 lists, we created four different versions, each comprising a different (random) by-item selection of words for the new Lexical Overlap conditions. (Chi-square tests showed no evidence of unevenly distributed word selections per condition, all $ps > .4$). Each of these 40 presentation lists was seen by two participants. As before, the trials per presentation list were presented in a pseudo-random order and spatial arrangements of words in the target arrays varied across items, but not across conditions.

Procedure, response annotation, and analysis

Apparatus, procedure, and response annotation were the same as in the previous two experiments, and analysis was the same as in Experiment 2.

Results

Overall Priming Results. Less than 1% of the prime-target pairings were excluded from analysis due to erroneous reading of the prime or failing to respond in the target, respectively. Table 7 shows the distribution of target responses (PO, DO, and Other) by Lexical Overlap (five levels) and Prime Structure (two levels) for the remaining 99% of valid cases.

Overlap	Prime	Target Response		
		PO	DO	Other
0-Word	PO	.439 (210)	.241 (115)	.320 (153)
	DO	.400 (190)	.316 (150)	.284 (135)
1-Word	PO	.502 (238)	.253 (120)	.245 (118)
	DO	.382 (182)	.358 (171)	.260 (124)
2-Word	PO	.657 (312)	.187 (89)	.156 (74)
	DO	.360 (172)	.431 (206)	.209 (100)
3-Word	PO	.735 (350)	.158 (75)	.107 (51)
	DO	.232 (110)	.629 (299)	.139 (66)
4-Word	PO	.881 (421)	.075 (36)	.044 (21)
	DO	.151 (71)	.777 (366)	.072 (34)
Total		.474 (2256)	.342 (1627)	.184 (874)

Table 7. Observed proportions of PO, DO, and Other target responses (absolute cell counts in brackets) for each Lexical Overlap \times Prime Structure combination in Experiment 3.

It becomes evident that Experiment 3 yielded very similar response patterns compared to Experiment 2: PO responses were generally preferred over DO responses, which in turn were more frequent than Other responses (bottom row of Table 7), and again, proportions of Other responses notably decreased (in favour of more PO and DO target responses) with increasing levels of Lexical Overlap between prime and target.

Across Lexical Overlap conditions, PO target responses were more likely after PO ($M = .643$) than after DO prime sentences ($M = .305$), and DO target responses were more likely after DO ($M = .502$) than after PO prime sentences ($M = .183$). Binary logistic GLMM analyses including Prime Structure as the only fixed factor (and with maximal random effects structure) confirmed the overall priming effect for

PO target responses ($\chi^2 = 137.88$, $df = 1$, $p < .001$) as well as for DO target responses ($\chi^2 = 129.37$, $df = 1$, $p < .001$).

Lexical Overlap and Structural Repetition. As before, the data were re-represented in terms of whether the structure of the prime was repeated in the target trial. Table 8 shows the corresponding probabilities across Lexical Overlap and Prime Structure conditions.

Overlap	Prime Structure		Mean
	PO	DO	
0-Word	.439	.316	.378
1-Word	.502	.358	.430
2-Word	.657	.431	.544
3-Word	.735	.629	.682
4-Word	.881	.777	.829
Mean	.643	.502	

Table 8. Probability of prime-structure repetition in the target trial for each Lexical Overlap \times Prime Structure combination in Experiment 3.

Due to the general PO bias in target response generation (cf. Table 7), PO prime structures were (again) associated with a higher likelihood of structural repetition in the target trial (bottom row of Table 8). More importantly, just as in Experiment 2, the likelihood of repeating the structure of the prime in the subsequent target trial increased as a function of the number of content words shared between prime and target.

As in the previous experiment, occurrences of structural repetition (versus no structural repetition, including Other) were modelled in terms of a full-factorial binary logistic GLMM. Prime Structure and Lexical Overlap were entered in mean-centered

form (deviation coding), and again, we used *backward difference coding* to split the Lexical Overlap predictor into four separate contrast variables (the 0-Word Overlap condition served as a baseline). The corresponding model parameters in Table 9 therefore represent *incremental contrasts*, comparing each Lexical Overlap level to the next lower-ranked level. To achieve convergence, random correlations were dropped from the (otherwise maximal) random effects structure of the model.

Parameter	Estimate	SE	Z	p
OVL_1	0.294	0.107	2.759	.006
OVL_2	0.600	0.107	5.629	<.001
OVL_3	0.784	0.136	5.767	<.001
OVL_4	1.088	0.146	7.446	<.001
Prime	0.821	0.232	3.536	<.001
OVL_1 × Prime	0.077	0.213	0.364	.716
OVL_2 × Prime	0.389	0.227	1.713	.087
OVL_3 × Prime	−0.565	0.233	−2.424	.015
OVL_4 × Prime	0.341	0.254	1.340	.180

Table 9. Fixed effect parameter estimates (in log odds units), Experiment 3. Occurrences of prime-structure repetition in the target trial were modelled by factor combinations of Lexical Overlap and Prime Structure. Parameters related to Lexical Overlap represent incremental contrasts (*backward difference coding*). OVL_1 = 1-Word Overlap; OVL_2 = 2-Word Overlap; OVL_3 = 3-Word Overlap; OVL_4 = 4-Word Overlap (Note: 0-Word Overlap served as baseline); Prime = Prime Structure (more positive means more structural repetition after PO primes).

As a result of the general PO-bias in target responses, there was a significant main effect of Prime Structure ($\chi^2 = 11.814$, $df = 1$, $p < .001$) indicating more structural repetition after PO than after DO primes. More importantly, there was also a very clear overall main effect of Lexical Overlap ($\chi^2 = 181.57$, $df = 4$, $p < .001$). As Table 9 shows, this was due to a significant increase in the probability of structural

repetition with every one-unit increase in the number of content words shared between prime and target. Lastly, the overall Lexical Overlap \times Prime Structure interaction was not reliable ($\chi^2 = 7.438$, $df = 4$, $p = .115$), but the corresponding estimates in Table 9 suggest that the change from 1-Word to 2-Word Overlap implied a marginally more positive lexical boost effect for PO rather than DO primes, whereas the change from 2-Word to 3-Word Overlap implied a significantly more negative lexical boost effect for PO compared to DO primes.

Discussion

Experiment 3 closely replicated the results from Experiment 2. Most notably, it showed an equally clear, monotonic increase in the strength of structural priming as a function of how many content words were shared between prime and target. Figure 2 compares the two experiments directly, plotting the mean probability of prime-structure repetition in the target trial as a function of the number of content words that were shared between primes and targets.

*** Figure 2 about here ***

The figure indicates that regardless of whether increasing levels of Lexical Overlap were manipulated in line with a particular constituent order (Experiment 2) or by selecting content words arbitrarily (Experiment 3), the results were roughly the same: with every additional content word – verb or noun – that was shared between prime and target, there was a significant increase in the likelihood of prime-structure repetition in the target trial by about 10% (modulo an apparently more quadratic growth characteristic in Experiment 3, as is also suggested by the increasing

incremental contrasts for the Lexical Overlap effect in Table 9)². We can therefore conclude that the cumulative lexical boost effect on PO/DO priming is largely driven by the *number* of content words shared between prime and target.

General Discussion

The lexical boost to structural priming has previously been taken as evidence for lexically-specific syntactic representations in the mental lexicon, most explicitly so in Pickering and Branigan's (1998) account of ditransitive structure priming. One theoretical implication of this account is that *licensing heads* of (potentially primed) structural alternatives should enjoy a privileged role in lexically boosting syntactic priming, even though lexical boost effects from non-head constituents have also been reported (McLean et al., 2004). This is because in (say) a verb phrase, it is the *verb* that projects combinatorial information about the numbers and types of arguments it requires (as well as their ordering) and not any of the argument nouns. Thus, it seems plausible to assume that repeating the verb between prime and target should lexically boost PO/DO priming even more than repeating any of the nouns.

Using a comprehension-to-production priming paradigm (cf. Ferreira, 1996) in which participants first read aloud a PO or DO prime sentence and then constructed a ditransitive sentence (from an array of randomly presented content words) in the target trial, the three experiments reported in this paper did not support the hypothesis that the verb enjoys a special role in lexically boosting ditransitive structure priming. Experiment 1 showed that the sharing of verbs between primes and targets did indeed lead to reliably stronger PO/DO priming (in line with many previous studies), but by

² The seemingly different growth characteristics are not necessarily due to the different Lexical Overlap manipulations. Note that the two experiments also differed in sample size (60 vs. 80 participants) meaning that condition-means were not equally robust. Since the issue is not critical to our main question, we refrain from following up on this further.

no means more so than the sharing of agent nouns or the sharing of recipient nouns, which boosted PO/DO priming equally strongly. Only shared theme nouns appeared somewhat less effective in boosting PO/DO priming when the data from Experiment 1 were considered (see also McLean et al., 2004). On the other hand, note that shared theme nouns did cause a substantial increase in PO/DO priming “on top of” Agent+Verb+Recipient Overlap in Experiment 2. Thus, the evidence concerning theme repetition appears somewhat mixed at present. More generally, Experiment 2 showed that an increase in the number of content words shared between primes and targets (in line with a particular sequencing of constituents) led to a significant, monotonic increase in PO/DO priming, and again, there was no convincing indication that the lexical boost associated with repeating the verb was different from the lexical boost associated with repeating nouns. Finally, Experiment 3 was able to replicate the cumulative lexical boost effect from Experiment 2 by increasing the number of shared content words between primes and targets in terms of arbitrary word selections (i.e., without following a particular sequence of constituents). Together, these findings experimentally demonstrate, for the first time, that lexical boost effects in syntactic priming are modulated by the *amount* of lexical content shared between primes and targets, but not by the particular *type* of content shared (specifically, structure-licensing heads vs. non-head constituents). Interestingly, corpus-based research has previously come to very similar conclusions regarding the non-preferential status of lexical heads in boosting structural priming (e.g., Reitter, Keller, & Moore, 2011; Snider, 2009).

At face value, it may appear tempting to conclude that the above would speak against lexically-specific representations of syntax in general. However, such a conclusion would be too short-sighted in our view. The existence of non-alternating

ditransitive verbs like *to donate* (which only permit PO structures: *he donated \$20 to them* / **he donated them \$20*) or *to fine* (which only permit DO structures: **he fined \$20 to them* / *he fined them \$20*) already indicates a theoretical requirement for lexically-specific syntactic representations. Moreover, related experimental support for lexicalization of (at least aspects of) syntax has been provided by Melinger and Dobel (2005) and by Salamoura and Williams (2006) who showed that the presentation of an isolated non-alternating verb (*donate*, *fine*, etc.) in a prime trial is already sufficient to bias PO/DO sentence production in a subsequent target trial that employs an alternating ditransitive verb (*sell*, *give*, *show*, etc.). There is also evidence that syntactic priming magnitudes depend on long-term structural preferences associated with alternating ditransitive verbs – more specifically, that priming becomes weaker (or stronger, when focusing on response times) for structures that agree with the verb's syntactic preference (e.g., Bernolet & Hartsuiker, 2010; Segaert, Weber, Cladder-Micus, & Hagoort, 2014). This, again, indicates a close relationship between verbs on the one hand and syntactic structures licensed by those verbs on the other. Taken together, it seems unreasonable to construe our findings as a challenge to lexically-specific structural representations.

However, what the present results do suggest rather vividly is that the *lexical boost* to syntactic priming (more structural repetition when content words are shared between prime and target) is not as compelling as, say, the investigation of verb-specific structural preferences for identifying lexicalized syntactic frames – contrary to what the model by Pickering & Branigan (1998) would imply (see also, e.g., Pickering & Branigan, 1999; Cleland & Pickering, 2003; Ferreira & Pickering, 2008). Lexical boost effects apparently indicate something else, and a suggestion of what this 'something else' might be has been proposed by Chang et al. (2006). They

conjectured that short-term lexical boost effects (which remain difficult to simulate via implicit learning even in more recent implementations of their model, see, e.g., Chang et al., 2012) may actually not be indicative of syntactic representations as such, but rather reflect an epiphenomenon related to explicit memory: when content words from the prime are repeated in the target trial, so their argument, they can act as memory cues to the original wording of the prime, which also creates a bias toward re-using the structure of the prime sentence. Indeed, the present data seem to fit very well with this proposal. First, this hypothesis does not inherently suggest any kind of ranking of constituents (e.g., licensing heads vs. non-heads) in terms of how important they are for boosting syntactic priming: *any* re-occurring content word in the target may serve as (roughly equally effective) retrieval cue to the wording and structure of the prime. Second, it may also be able predict ‘cumulative’ lexical boost effects (cf. Experiments 2 and 3): the more cues (i.e., shared content words between primes and targets) there are, the better the memory for the wording and structure of the prime should be. Apart from coping well with the present findings, this hypothesis can also explain why lexical boost effects do not interact with the syntactic positioning of a repeated lexical head of a sentence, as recently shown for German sentence production (Chang, Baumann, Pappert, & Fitz, 2015). Lastly, the proposal by Chang et al. (2006) would even predict lexical boost effects for the priming of structural alternatives that do not rely on lexically-specific syntactic frames, such as high versus low relative clause attachment in sentences like *I met a friend of a colleague who lived in Dundee* (e.g., Scheepers, 2003; Desmet & Declercq, 2006). The latter has not been tested yet, but could be an interesting avenue for future research.

Interpreting our findings in terms of Chang et al.'s (2006) *dual mechanism* account naturally raises a number of further questions that are difficult to answer at present. For example, how does the memory mechanism responsible for lexical boost effects actually look like and what are the kinds of representations involved (syntax, semantics, lexicon, phonology)? How exactly would facilitated recall of a prime sentence increase the tendency to re-use its structure in a subsequent target trial? Unfortunately, the available evidence does not yet offer conclusive answers to these important questions. However, it appears that at least some aspects of the current findings are not without precedent in the memory literature. In one notable set of studies (Shiffrin, Murnane, Gronlund, & Roth, 1989), participants read study sentences like *the alert boy found the magic sword* before being prompted to recall one of the words using a retrieval template like *the alert ____ found the ??? sword* (where ??? highlights the to-be-recalled word and ____ indicates that an additional word from the study sentence has been blanked out). Among other variables, the authors varied the number of content words (contextual cues) available in the retrieval templates. Interestingly, the findings indicated that recall accuracy increased monotonically as a function of the number of content words available in the retrieval templates, whereas their constituent roles or relative orderings were not important. One way to interpret these findings is that participants retain some form of shallow surface representation of the original study sentences, aspects of which become more retrievable via the provision of more contextual cues. Applied to PO/DO priming, one could hazard the conjecture that along with an abstract syntactic representation, participants also retain a more shallow surface-representation of the prime sentence, details of which might include, e.g., whether the verb is followed by an animate or inanimate noun, or whether or not the sentence contained a preposition ("to"

respectively “for”). Such details would be easier to recall and reproduce if content words from the prime are repeated in the target trial, thereby supporting (or facilitating) abstract structural priming. Obviously, due to the lack of more specific evidence, such a proposal must remain rather vague and speculative at present. Providing a detailed mechanistic account of the *lexical boost as explicit memory phenomenon* therefore poses an important challenge for future research.

What about other possible ways to explain the present findings? One suggestion might be to simply extend Pickering and Branigan’s (1998) original account by assuming that not only verbs, but also nouns may link to combinatorial nodes encoding PO/DO structures. We believe that there are strong theoretical reasons against such a proposal. Unlike verbs, nouns can play various syntactic and semantic roles in a sentence (leaving aside animacy restrictions on certain thematic roles), and there is a vast variety of different sentence structures that nouns can be part of. Encoding this in an extended version of Pickering and Branigan’s (1998) model would require that every single noun would link to (almost) every slot in every combinatorial frame that the grammar of a given language has on offer. Although this could explain the present findings (just as the empirical coverage of a boxes-and-pointers model is likely to improve after adding more pointers), the resulting network of lemma and combinatorial nodes would end up encoding mere *associations*. That is, the model would essentially lose its ability to express meaningful grammatical relations between specific word lemmas on the one hand and syntactic structures licensed by those word lemmas on the other (i.e., the very aspect that made Pickering and Branigan’s account so appealing from a linguistic point of view).

In line with Chang et al. (2006), we therefore suggest that it makes more sense to theoretically separate structural priming *per se* from lexical boost effects on

structural priming: the former tells us something about the learning and/or activation of syntactic representations, while the latter might reflect an additional memory-related phenomenon – a very useful phenomenon nonetheless, as it helps to enhance the detectability of often rather subtle syntactic priming effects (see Mahowald et al., 2016). Such a theoretical separation also concurs with another qualitative distinction, first noted by Hartsuiker et al. (2008): while syntactic priming effects persist over time, lexical boost effects on syntactic priming tend to decay fairly rapidly. Again, this suggests that the underlying cognitive mechanisms are not the same.

Treating the lexical boost as theoretically distinct from structural priming *per se* has potentially important implications for other areas of psycholinguistic research. To give an example, there has been a long-standing debate in the language development literature as to whether structural representations acquired early in life are lexically-specific or indeed more abstract. Some of the arguments surrounding this question have been based on the presence or absence of (predominantly verb-related) lexical boost effects on structural priming in children of various age groups (for recent discussions see, e.g., Branigan & McLean, 2016; Foltz, Thiele, Kahsnitz, & Stenneken, 2015; Morris & Scheepers, 2015; Peter, Chang, Pine, Blything, & Rowland, 2015; Rowland, Chang, Ambridge, Pine, & Lieven, 2012). Inasmuch as they rely on the premise that lexical boost effects are indicative of lexicalized syntactic frames, such arguments become less compelling when the present findings are considered.

In conclusion, we wish to stress the message expressed in the title of this paper: the lexical boost to structural priming should not be regarded as being diagnostic of lexically-specific syntactic representations, even though such representations make a lot of sense for reasons other than the lexical boost (most

notably, the existence of lexically-specific structural preferences or outright lexical restrictions). Indeed, separating lexical boost effects from structural priming *per se* would appear to offer clear theoretical and empirical advantages to the field.

Author Notes

Data and analysis scripts can be downloaded following this link:

<http://www.psy.gla.ac.uk/~christop/LexOverlap.zip>.

This research was funded by ESRC research grant RES-000-22-2295 awarded to CS.

AM acknowledges support from Russian Academic Excellence Project 5-100.

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Appendix A

Experimental items used (N = 60). Only the PO prime condition (full sentences) and the No Overlap target condition (words in curly brackets) are shown. Intended agent nouns (underscored) were highlighted by a distinct font colour, and the target words were randomly arranged on screen (see text).

The secretary tossed the stapler to the officemate {manager, forwarded, contract, employee}

The cashier sold the blade to the customer {farmer, handed, tool, mechanic}

The murderer mailed the knife to the reporter {lunatic, offered, cash, messenger}

The agent rented the apartment to the businessman {skier, loaned, equipment, visitor}

The sportsman showed the frisbee to the mate {teacher, took, headpiece, clown}

The blackmailer brought the secret to the sergeant {childminder, told, story, cobbler}

The dignitary passed the letter to the fan {footballer, wrote, email, girl}

The chatterbox lent the badge to the teammate {instructor, flung, ball, captain}

The cardinal sent the envelope to the jury {editor, gave, manuscript, critic}

The busybody offered the cookie to the postman {evangelist, sold, bible, youngster}

The mountaineer loaned the helmet to the hiker {engineer, tossed, bandage, colonel}

The supervisor posted the CD to the linguist {librarian, rented, volume, undergrad}

The salesman showed the merchandise to the housewife {landlord, mailed, document, tenant}

The drug dealer forwarded the money to the broker {juvenile, lent, pistol, policeman}

The backpacker wrote the postcard to the roommate {optimist, threw, letter, trustee}

The elf loaned the treasure to the pixie {king, forwarded, goblet, giant}

The spectator flung the bat to the player {hero, brought, coin, father}

The baker gave the loaf to the beggar {vicar, tossed, cheque, nephew}

The kidnapper threw the gift to the blonde {diplomat, posted, kit, spy}

The Mexican passed the gun to the sheriff {accomplice, lent, hat, doorman}

The rapper showed the lyrics to the activist {hippie, sent, money, prisoner}

The lawyer handed the tape to the authority {driver, rented, van, companion}

The tycoon took the rumour to the journalist {witness, told, account, detective}

The priest wrote the rhyme to the peasant {dame, posted, note, bellboy}

The storyteller told the ending to the toddler {interpreter, gave, meaning, stranger}

The partner flung the bouquet to the shoplifter {hobo, sold, ipod, sightseer}

The jockey sent the whip to the trainer {cowboy, threw, rope, barman}

The junkie offered the needle to the callgirl {midget, passed, banknote, playboy}

The sponsor mailed the copy to the champion {buddy, handed, T-shirt, cheerleader}

The admirer brought the present to the singer {promoter, took, whiskey, boxer}

The babysitter got the bonnet for the child {housekeeper, saved, biscuit, guest}

The matron sewed the cap for the toddler {granny, kept, scarf, orphan}

The stud bought the steak for the VIP {friend, ordered, soup, teenager}

The amateur painted the watercolour for the heiress {insider, got, reproduction, conman}

The chef prepared the cod for the celebrity {maid, caught, quail, politician}

The Viking built the ship for the master {courtier, designed, throne, tyrant}

The counsellor hired the room for the victim {constable, found, car, woman}

The thief fetched the wheelbarrow for the farmhand {lad, painted, motorboat, husband}

The trucker saved the curry for the neighbour {surfer, cooked, burger, girlfriend}

The gypsy bought the outfit for the acrobat {mogul, organized, cigar, veteran}

The governess knitted the jumper for the genius {grandmother, fetched, blanket, fugitive}

The cook ordered the bread for the president {aide, baked, cake, admiral}

The convert got the robe for the guru {tailor, sewed, suit, rabbi}

The nanny painted the kite for the brat {uncle, made, plane, nerd}

The midwife prepared the bed for the patient {cleaner, saved, stew, mother}

The confectioner baked the tart for the bishop {adulterer, kept, dish, lover}

The attendant reserved the dress for the winner {godmother, knitted, bag, schoolgirl}

The nurse ordered the bow-tie for the surgeon {wife, hired, jacket, patron}

The director booked the lodge for the soprano {organist, organized, waltz, delegate}

The keeper caught the salmon for the hostage {servant, cooked, rabbit, empress}

The madman bought the shield for the commander {blacksmith, made, axe, lumberjack}

The henchman found the crypt for the baron {nomad, built, mosque, sultan}

The maiden made the muffin for the dwarf {goblin, baked, wafer, brute}

The sidekick booked the trousers for the magician {seamstress, sewed, costume, clergyman}

The novice cooked the lobster for the mayor {waiter, reserved, sausage, writer}

The robber fetched the dinner for the gangster {student, booked, scooter, tourist}

The substitute hired the drill for the dentist {apprentice, prepared, bench, craftsman}

The captive knitted the shawl for the witch {widow, found, yarn, nun}

The eccentric kept the nightingale for the emperor {warrior, caught, elephant, ringmaster}

The hunter designed the birdcage for the princess {footman, painted, palace, vampire}

Appendix B

A potential concern might be whether the current experimental paradigm was actually capable of detecting structural priming effects in the absence of lexical overlap between primes and targets. We therefore conducted a supplemental analysis focusing only on data in the baseline conditions (without any lexical overlap) which were in fact identical across all three experiments. We pooled the relevant data from Experiments 1, 2 and 3 together and excluded less than 1% of cases where participants read the prime sentence incorrectly or failed to respond in the target trial. Since, for conditions without lexical overlap, mean probabilities of Other responses were roughly equal across experiments (.276, .279, and .302 for Experiment 1, 2 and 3, respectively) as well as across Prime Structure conditions (.285 and .286 for the PO and DO prime conditions, respectively), we excluded Other responses such that proportions of PO target responses were now complementary to proportions of DO target responses. Considering these data, probabilities of producing PO/DO target responses were .674/.326 in the PO Prime Structure condition, compared to .631/.369 in the DO Prime Structure condition. A binary logistic GLMM with Prime Structure as the only fixed factor (and maximal by-subjects [N=200] and by-items [N=60] random effects structure) confirmed that this proportional change was significant ($\chi^2 = 25.590$, $df = 1$, $p < .001$).³ Hence, all three experiments combined were clearly able to register a lexically-independent structural priming effect. However, as mentioned earlier in the paper, each experiment on its own was probably not powerful enough to detect it.

³ When a factorial Experiment \times Prime Structure fixed effects design was used (see commented *R* script in online materials), results were as follows: the overall effect of Prime Structure remained significant ($p < .001$), but there was also a main effect of Experiment ($p < .001$) due to a weaker PO target response bias in Experiment 3 than in the other two experiments; the Experiment \times Prime Structure interaction was not reliable ($p = .123$).

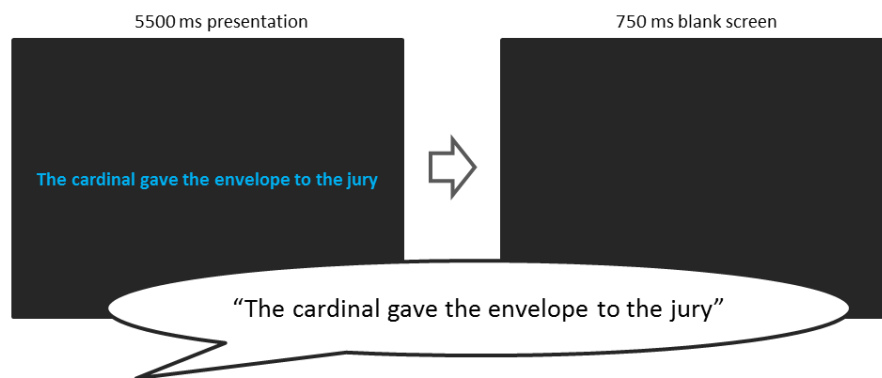
When compared to results from confederate-scripted dialogue experiments or even sentence completion studies, our experiments obviously showed weaker evidence for lexically-independent structural priming. Two potential factors might have contributed to this. One is that our task was somewhat more taxing: Our participants had to generate their responses within 6.5 seconds from the onset of each target trial, and the words for sentence generation were always presented in a scrambled fashion (see bottom panel of Figure 1). A second contributing factor might be that the present technique allowed for more syntactic flexibility in responding, as suggested by the relatively high proportions of Other responses in the No Overlap conditions (close to 30% in each experiment). Whatever the main reason for the weak (but detectable) abstract structural priming effects in our paradigm, the main analyses in the paper show that these effects were clearly enhanced via sharing of lexical content between primes and targets.

Figure Captions

Figure 1. Illustration of reading aloud trials (top panel) versus sentence generation trials (bottom panel)

Figure 2. Experiments 2 and 3 compared. Mean probability of prime-structure repetition in the target trial is plotted against the number of content words shared between primes and targets.

Reading Aloud Trial (Prime)



Sentence Generation Trial (Target)

